High p_T Away-side Suppression with Respect to the Reaction-Plane in Au+Au $\sqrt{s_{NN}}$ = 200 GeV

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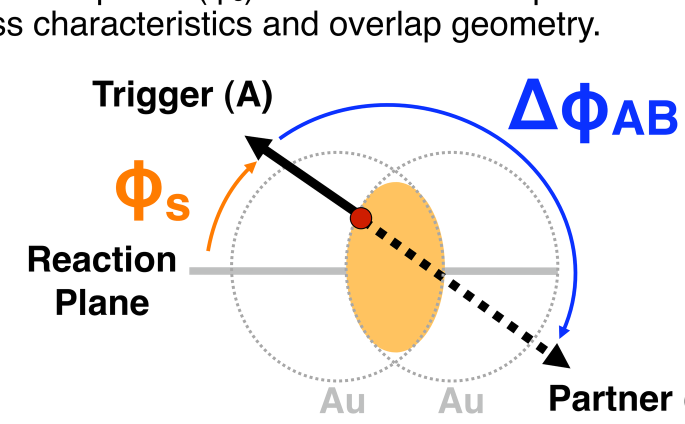
Abstract

Away-side high p_T pair correlations in heavy ion collisions made above the medium response at intermediate p_T can be used to study the nature of parton energy loss and system geometry. Varying the jets with reaction plane angle changes the path length through a medium at fixed average density, something that cannot be done via centrality selection. Furthermore, the dependence of the away-side yields on reaction plane angle differ if the dominate source of away-side pairs is produced by partons "punching through" (crossing the nuclear-overlap) versus models where complete energy loss limits away-side production to back-to-back partons tangential to the nuclear overlap.

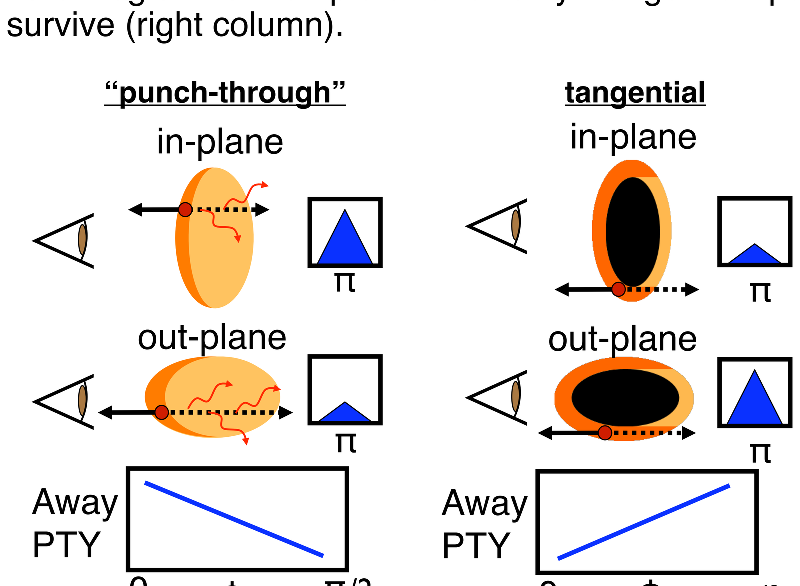
This analysis uses pairs made between triggers of neutral pions between 4.0-7.0 GeV/c and charged hadrons between 3.0-4.0 and 4.0-5.0 GeV/c to construct per-trigger yields for near- and away-side jets. In mid-central (20-60%, b = 9 fm) collisions, we find a flat dependence for near-side production by reaction plane angle, the expectation for surface-biased emission. However, away-side yield falls steeply for both partner p_T windows. These falling trends demonstrate punch-through production dominance over tangential production in mid-central collisions. These results also present a challenge to theories that predict weak variation with respect to reaction plane angle.

Motivation

Pairs between final-state particles above ~ 4 GeV/c have previously been shown to be dominated by jet fragmentation [1]. A study of away-side ($\Delta\phi_{AB} \approx 180°$) suppression by azimuthal angle with respect to the reaction-plane (ϕ_s) can be used to probe of energy-loss characteristics and overlap geometry.

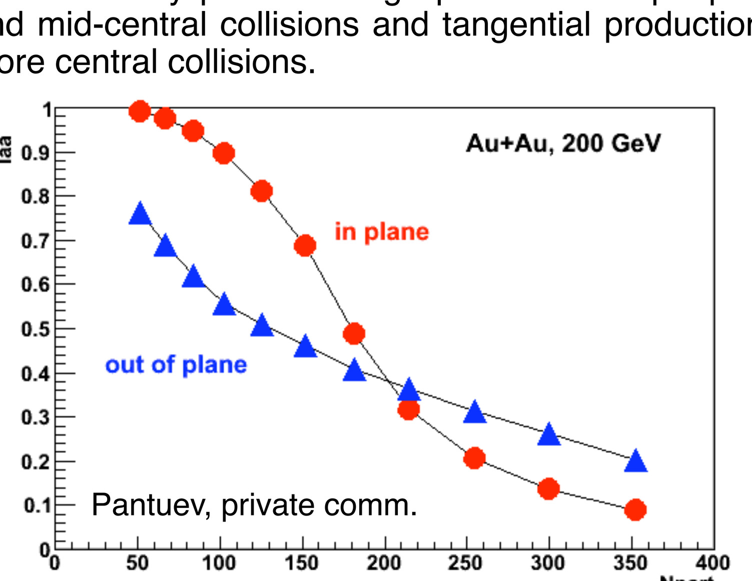


Two kinds of production may contribute to the surviving back-to-back jet pairs. The first kind, "punch-through" (nuclear overlap crossing) production, is shown in the left column of the figure below. Nuclear overlap crossing production may occur if away-side partons lose only some fraction of their energy or if only a fraction of the away-side partons are completely suppressed. Production of the second kind is tangential and occurs in all cases. This production may dominate if energy loss of all partons entering a core region is complete and only tangential pairs survive (right column).



"Punch-through" production is increasingly suppressed as the path-length through the nuclear overlap is increased. Tangential production, which is a function of the integrated corona density, will have the opposite dependence with ϕ_s.

Two sets of theoretical predictions for away-side suppression are shown for mid-central Au+Au collisions. Thorsten Renk has made away-side suppression calculations for punch-through production. The closest of which is for 12-20 GeV/c triggers paired with 4-6 GeV/c partners and impact parameter 7.5 fm and has a weak dependence on reaction plane [2]. Vlad Pantuev has also made a prediction for away-side suppression shown below [3]. In this model, a black-core formation time drives the transition between dominance by punch-through production in peripheral and mid-central collisions and tangential production in more central collisions.



Method

Measured pairs are assumed to correlate trivially (two particles within the same event see the same event-plane) or correlate via the same hard-scattering process. This two-source model assumption is expressed as:

$$C(\Delta\phi) = J(\Delta\phi)) + b_0^{ZYAM}\left(1 + \frac{\beta}{\alpha}\cos(2\Delta\phi) + \frac{\gamma}{\alpha}\cos(4\Delta\phi)\right)$$

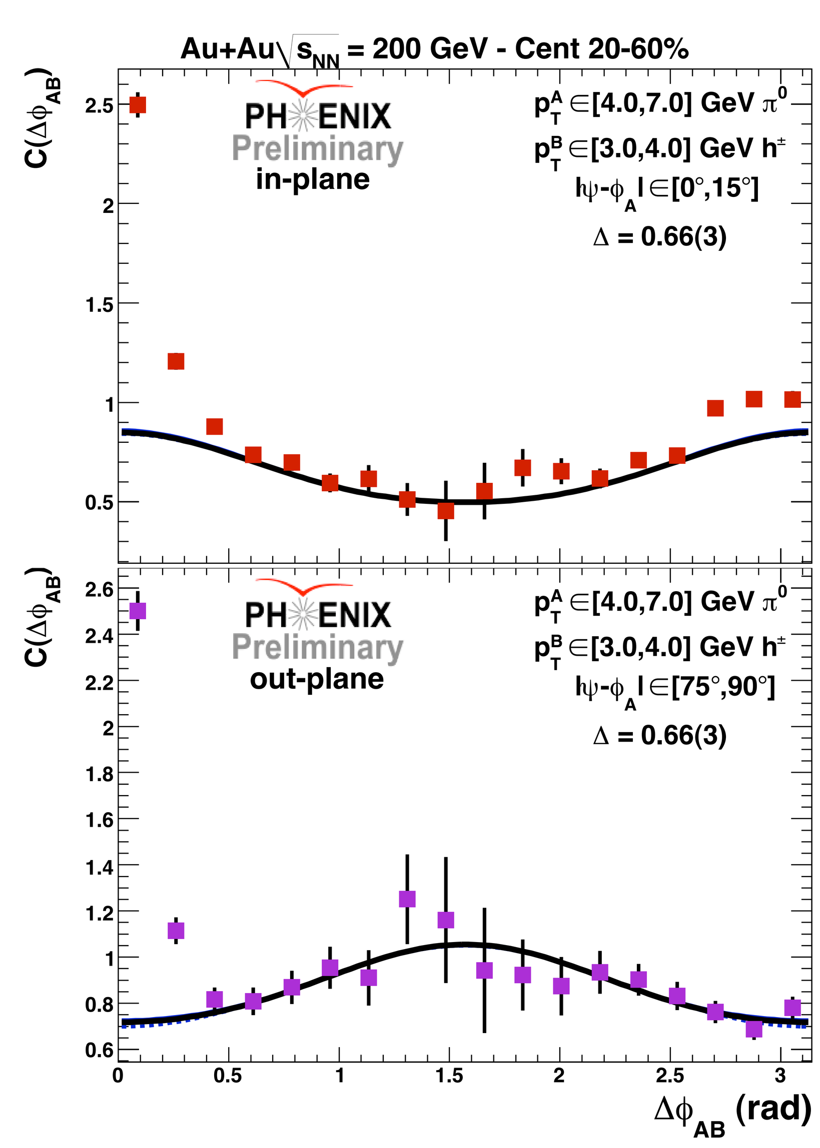
where the modulation variables from [4] are:

$$\alpha = 1 + 2v_2^A cos(2\phi_s)\frac{sin(2c)}{2c}\Delta + 2\,v_2^A cos(4\phi_s)\Delta_4$$

$$\beta = 2v_2^A v_2^B + 2v_2^B\left(1+v_4^A\right)cos(2\phi_s)\frac{sin(2c)}{2c}\Delta + 2v_2^A v_2^B cos(4\phi_s)\frac{sin(4c)}{4c}\Delta_4 + 2v_2^B v_4^A cos(6\phi_s)\frac{sin(6c)}{6c}\Delta_6$$

$$\gamma = 2v_4^A v_4^B + 2v_4^B\left(1+v_2^A\right)cos(4\phi_s)\frac{sin(4c)}{4c}\Delta_4 + 2v_2^A v_4^B\left(cos(2\phi_s)\frac{sin(2c)}{2c}\Delta + cos(6\phi_s)\frac{sin(6c)}{6c}\Delta_6\right) + 2v_4^A v_4^B cos(8\phi_s)\frac{sin(8c)}{8c}\Delta_8$$

These account for reaction-plane binning and resolution effects on the underlying event shape. Given sufficient resolution and narrowness of binning, the shape modulation will flip sign between in-plane and out-of-plane bins. This effect is demonstrated in the figure below.



The elliptic (v_2) and hexadecapole (v_4) terms are measured for both trigger and partner particles by Fourier decomposition of the singles distributions with respect to the reaction plane. The systematic uncertainties on the underlying event modulation are of two kinds: those that correlate with ϕ_s and those that anti-correlate with ϕ_s. Uncertainties of both kinds are propagated and found to be negligible at these transverse momenta.

The underlying event normalization (b_0) has been determined via the Zero Yield at Minimum (ZYAM) assumption. In the procedure, the correlations are fit to a functional form containing a near-side Gaussian, an away-side Gaussian, and a flow term as described above. The well-separated near-side and away-side jet production gives a broad region over which the underlying event contribution dominates.

Normalization uncertainty from the ZYAM procedure is estimated via a fast Monte Carlo using the measured statistical precision as input. The extracted uncertainty is small, but fully correlated along $\Delta\phi_{AB}$. These values are depicted as dashed bands about 0 on the subtracted jet functions shown in the next section.

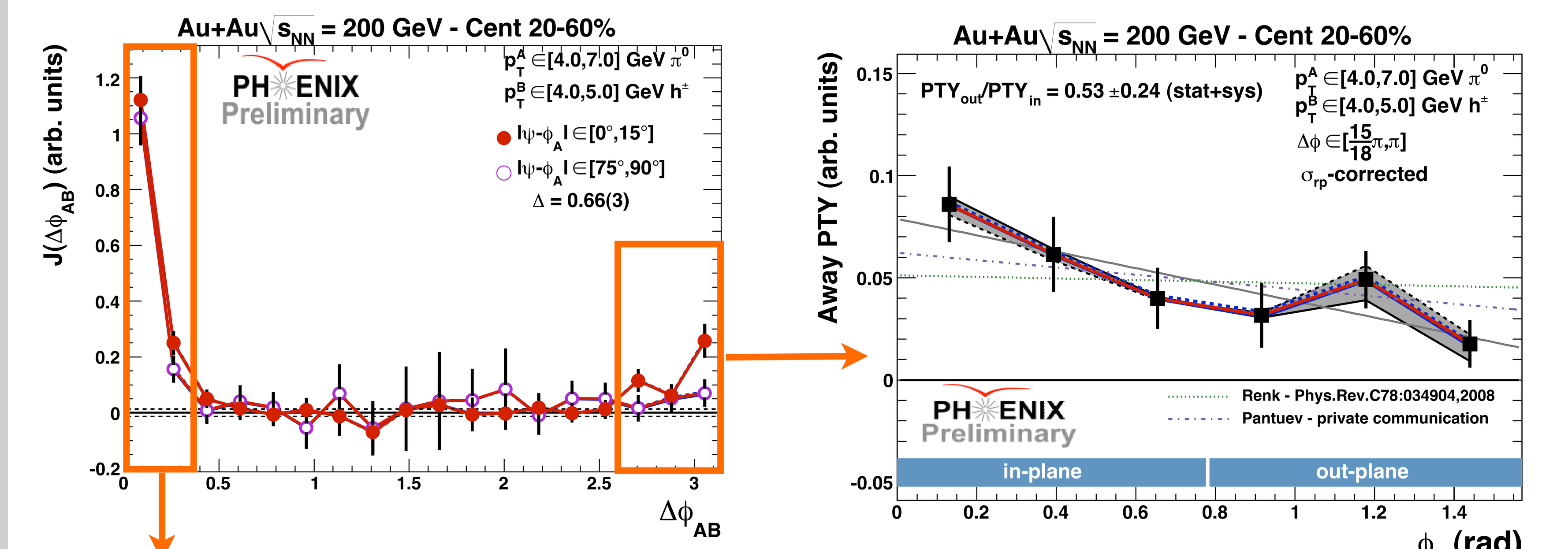
Near- and away-side Per-Trigger-Yields (PTY) are found by integrating across $\Delta\phi_{AB}$ windows that approximate 2σ jet-widths as measured from reaction-plane summed distribution. This choice is made to reduce the effect of decreased precision near $\Delta\phi_{AB}$ = 90° and the influence of the $\Delta\phi_{AB}$-correlated ZYAM uncertainty. These windows introduce little bias as little jet-yield remains outside the selections.

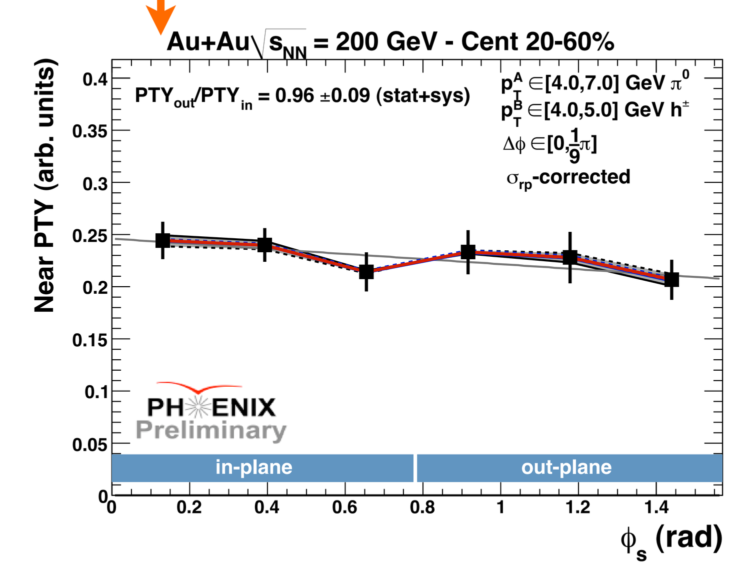
Near- and away-side PTY by ϕ_s distributions are corrected for the smearing caused by the reaction-plane resolution. The uncertainty from the resolution-correction is shown as a gray systematic band and is fully anti-correlated along ϕ_s.

References

[1] A. Adare, *Phys. Rev. C* **78**:014901 (2008)
[2] T. Renk, *Phys. Rev. C* **78**:034904 (2008)
[3] V. Pantuev, *Proc. 22nd WWND*, 2006
[4] J. Bielcikova *et al.*, *Phys. Rev. C* **69**:021901 (2004)

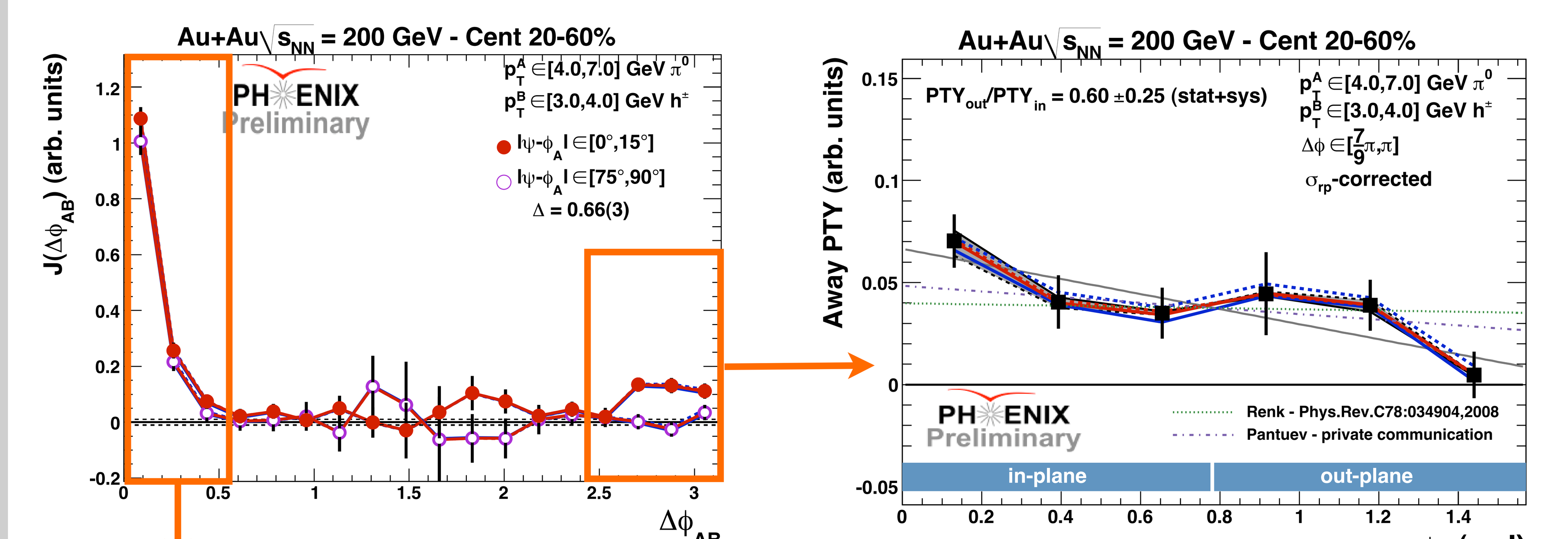
Results

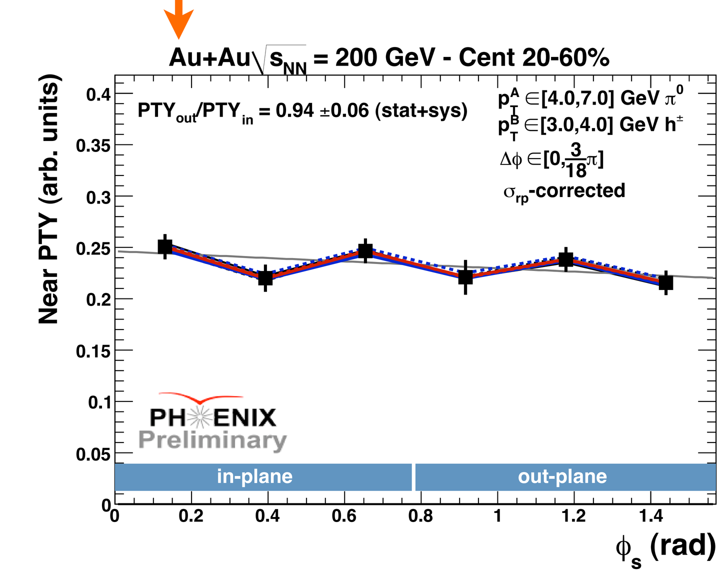




Charged Hadron Partners 4-5 GeV/c:

Subtracted jet functions (upper left) for most in-plane (red) and most out-of-plane (violet) 15° ϕ_s bins. These jet functions share a common arbitrary vertical scale. Integration windows for near- and away-side PTYs are indicated by orange boxes. Near-side PTY (left) is 0.5σ from a flat dependence. The away-side PTY (upper right) is steeply falling with greater significance. The systematic uncertainty on the reaction-plane resolution unsmearing correction is plotted as a gray band. Other flow systematics (vanishingly small) are shown as blue and red bands.



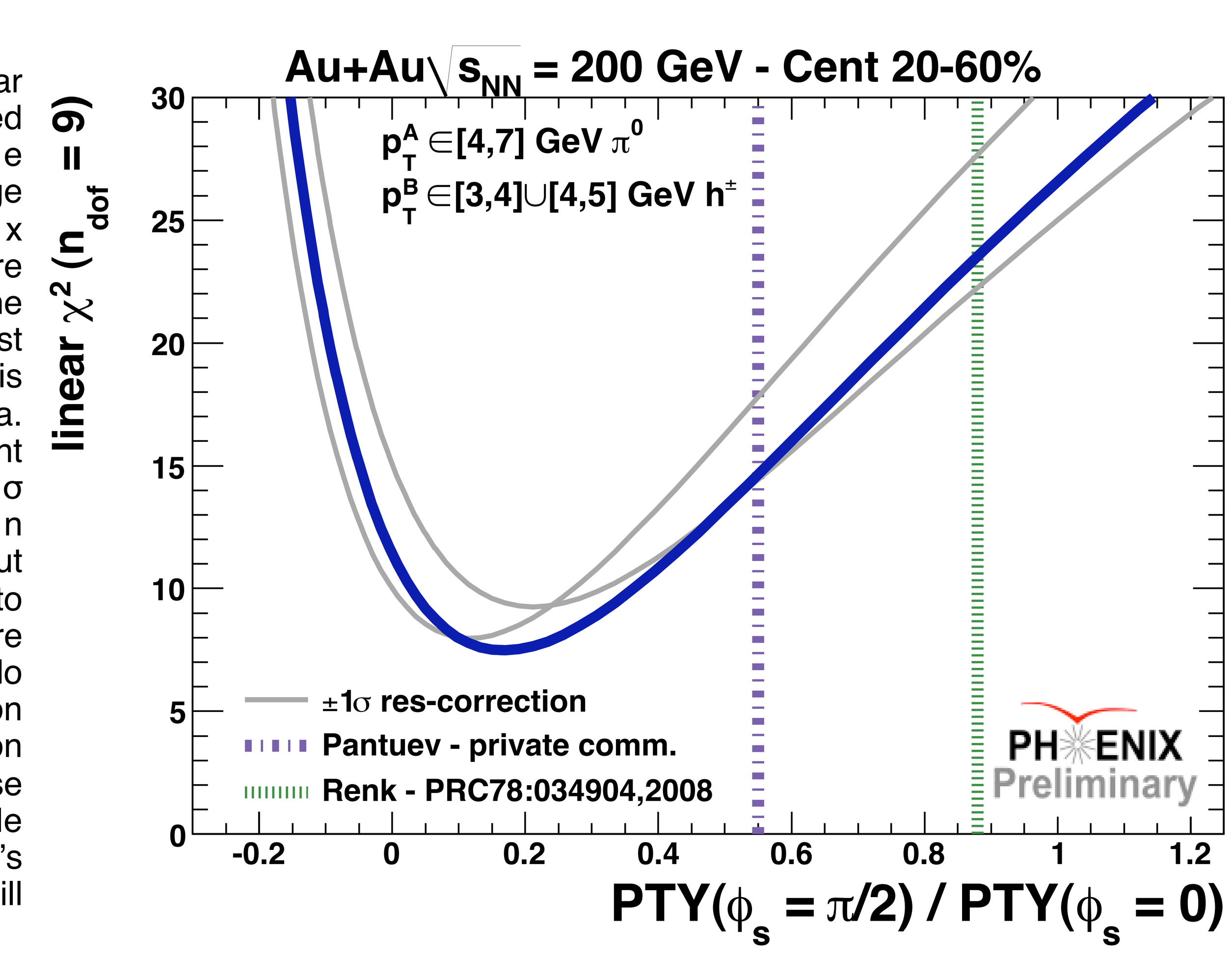


Charged Hadron Partners 3-4 GeV/c:

Identical to above, now for lower partner momenta. Integration windows are wider to account for the wider jet-width at lower p_T. Near-side PTY is 1σ from a flat dependence. Again, the away-side PTY is steeply falling with greater significance. Emerging reaction-plane resolution error fully-correlated along ϕ_s (blue lines) plays only a small role in slope variations and is treated as negligible. Anti-correlating flow determination uncertainty (red lines) remains vanishingly small.

χ^2 Distribution:

Composite χ^2 distribution for linear fits to both of the aforementioned partner momenta under the assumption of identical percentage variations in the away-side PTY x ϕ_s measurements. Variations are reported as the ratio of PTY at the extrema of most in-plane and most out-of-plane. A χ^2/dof of 0.8 is found for the best fit to the data. The gray lines show the agreement of fits made against the ±1σ reaction-plane resolution corrections. The data rule out rising variations (values above 1) to many σ. The data also prefer more strongly falling variations and do not rule out complete suppression for ϕ_s = 90°. Renk's prediction (made for higher p_T than these measurements) are incompatible with these data [2]. Pantuev's prediction is a closer match but still weaker than these data [3].



Conclusions

We have shown that away-side suppression increases with increasing angle with respect to the reaction plane in mid-central Au+Au 200 GeV collisions. This dependence tells us that the surviving back-to-back pairs in mid-central collisions originate from partons that have crossed the nuclear overlap and not from partons emitted tangentially to the surface of the medium. As spectral slopes of back-to-back high p_T pairs are known not to change with collision centrality from p+p values [1], it is likely that some fraction of partons are crossing the nuclear overlap with little energy loss.

The steep dependence measured presents a challenge for theories that predict only a weak dependence of away-side suppression with respect to the reaction plane. Many theories that otherwise describe the overall level of nuclear suppression of both singles and pairs in heavy ion collisions may be able to describe this data by implementing initial state distributions for soft production that contain additional anisotropy. Thus these data may play an important roll in further constraining the geometry of the initial state in heavy ion collisions. The geometric distribution of soft production is a topic of considerable interest as it is an important input for the determination of the role of viscosity in heavy ion collisions.

We note that despite being above known intermediate p_T "medium-response" effects (p_T > 4 GeV/c), these data lie within transverse momenta that may contain recombination effects (p_T < 6 GeV/c).

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